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A comprehensive review on pool boiling of nanofluids

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HIGHLIGHTS

- A review on the pool boiling heat transfer of nanofluid is presented and discussed.
- Nanoparticle deposition considerably affects the boiling heat transfer.
- The HTC decreases due to the low contact angle and the high adhesion energy.
- The HTC increases due to the formation of the new cavities and liquid suction.
- The CHF increases due to the increase in roughness, wettability and capillarity.

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ABSTRACT

Nanofluids are nanoparticle suspensions of small particle size and low concentration dispersed in base fluids such as water, oil and ethylene glycol. These fluids have been considered by researchers as a unique heat transfer carrier because of their thermophysical properties and a great number of potential benefits in traditional thermal engineering applications, including power generation, transportation, air conditioning, electronics devices and cooling systems. Many attempts have been made in the literature on nanofluid boiling; however, data on the boiling heat transfer coefficient (HTC) and the critical heat flux (CHF) have been inconsistent. This paper presents a review of recent researches on the pool boiling heat transfer behaviour of nanofluid. First, the development of nanofluids and their potential applications are briefly given. Then, the effects of various parameters on nanofluids pool boiling are discussed in detail.

1. Introduction

1.1. Development of nanofluids

Today in the heat transfer technology there are demand that devices should be with high heat flux, high precision and occupy minimum space. In these devices with high heat fluxes, air based cooling systems are not sufficient, and therefore liquid cooling systems are preferred. While single-phase liquid cooling is limited to a few hundred W/cm^2 for practical systems, two-phase (boiling) liquid systems provide cooling heat fluxes of several thousand W/cm^2 [1]. Therefore, boiling is one of the most effective heat transfer modes encountered in many industrial applications including power plants, refrigeration systems, heat-exchanger systems and electronic device cooling systems. Classic heat transfer fluids such as air, water, oil and ethylene glycol (EG) are used as the working fluids in these applications. Thermophysical properties of working fluids play a crucial role for the enhancement of heat transport. However, poor thermal properties of conventional heat transfer fluids limit the system performance. Thus, these fluids are not suitable for meeting the growing cooling demand of heat removal in high energy devices.

Thanks to modern technology, many types of particles with nanometer scale can be produced by physical or chemical synthesis techniques. A nanometer is a billionth of a meter (10^{-9} m), or around 100,000 times finer than the average human hair. Moreover, nanometers are used to measure very tiny things such as the wavelength of light and the size of atoms. A substance at nanoscale exhibits very different properties from those of bulk material. Thus, recently, many scientists have given importance to nanomaterials in related fields such as heat and mass transport processes. The chart in Fig. 1 has been constituted by using both keywords 'nanofluid' and 'boiling'. As seen in Fig. 1, there is a rapid growth in nanofluid boiling researches in recent years.

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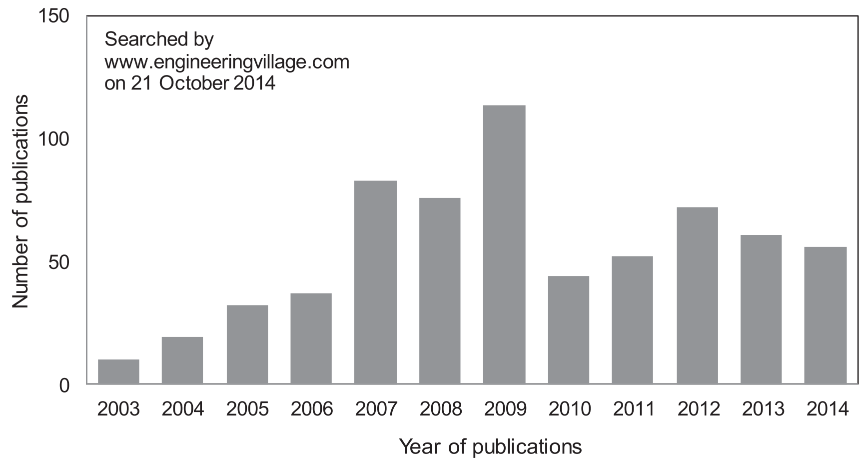

Fig. 1. Nanofluid publication rate.

Nanofluids have emerged as a new type of heat transfer fluid. They are colloidal suspensions containing a very small amount of nanometer sized particles suspended in conventional heat transfer fluids [2]. Commonly used nanoparticles are metal (silver, gold, copper and iron), metal oxide (alumina, copper oxide, silica and titania) and non-metal (carbon nanotubes and diamond) particles with sizes below 100 nm. Two main techniques are used for producing nanofluids, one- and two-step method. The first represents the direct formation of the nanoparticles in a base fluid. The second represents the preparation of nanoparticles separately mixed into the base fluid. In either case, pH control, use of surfactant and ultrasonic vibration can be applied to achieve a stable suspension. Compared to the fluids containing milli- or micro-sized particles, nanofluids exhibit superior heat transfer performance as well as better stabilization. The main reasons are higher surface area and higher thermal conductive capability than the base fluid. Previous researches have shown that nanofluids have a great potential for heat transfer enhancement in many fields such as power generation, electronic, automotive, manufacturing, medical and chemical industries and so on.

1.2. Potential applications of nanofluids

Nanofluids can be used to ensure the improved heat transfer and energy efficiency in a wide variety of thermal management systems such as nuclear reactors [3–5], ultrafast electronic cooling systems [6–8], solar collectors [9,10], microelectronics [11,12], heating, ventilation and air-conditioning (HVAC) systems [13] and automotive industries [14,15]. For example, they can increase the thermal transport properties of coolants and lubricants in the spark and compression ignition engines [14]. Nanofluids with high thermal conductivity can provide significant energy and cost savings [13]. Furthermore, they have a high potential for miniaturized systems that require smaller inventories of fluids [11]. Therefore, nanofluids make the thermal systems smaller and lighter. In the following section, a summary of nanofluid applications based on available literature is given.

1.2.1. Nuclear reactor applications

The engineers in nuclear energy industry are continuously being studied to increase the power density, efficiency, reliability and safety systems of the reactors. In a pressurized water reactor (PWR), the increase of CHF between the fuel rod and the water can provide an advantage to achieve their goals [16,17]. In the case of nanofluids instead of water, the fuel rods would be coated with nanoparticles and the CHF would significantly increase [18,19].

1.2.2. Electronic applications

Due to their high thermal conductivity, nanofluids can also be used for cooling applications of miniaturized high heat flux components [20,21], such as high speed computing microchips [22]. Because nanofluids can flow in microchannels without clogging, they would be suitable coolants [23,24]. Therefore, the devices would operate not only with high precision but also occupy minimum space [25,26].

1.2.3. Automotive applications

It is well known that the traditional heat transfer fluids such as engine oils, coolants or lubricants used in radiators, engines, HVAC of conventional automotive systems have relatively poor heat transfer properties [15]. Therefore, the use of nanofluids as coolant and additive in fuel and brake fluids provide benefits on the system performance due to high thermal conductivity, as well as the smaller system size. For example, the preliminary tests of the cooling system of an engine indicate that the use of nanofluid instead of conventional engine coolant (i.e. water-EG mixture) would provide significant benefits by removing more heat from the engine [27]. Furthermore, lubricants including nanoparticle show better lubrication properties and less wear on the segments of the cast iron cylinder liner and piston skirt at 100 °C. It is well known that high lubrication performance increases the life time and the fuel economy of internal combustion engines. This offers an opportunity for engineers to develop engines that are smaller, cheaper and lighter, resulting in less emissions for a cleaner environment [28,29].

1.2.4. Biomedical applications

Nanofluids and nanoparticles play a crucial role in biomedical applications [30,31]. For example, nanofluids including iron nanoparticles can be used to diagnose cancer and to deliver the drugs or radiation in cancer patients without damaging the healthy tissue. Magnetic nanoparticles can move the tumour tissue by applying a magnetic field outside the body. Moreover, because these particles are more adhesive to tumour cells than healthy cells due to their surface properties, they are promising for medical applications, ensuring new cancer treatment techniques [32,33].